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Adaptive interference mitigation in multi-cell RIS-Massive MIMO system for 6G systems

Sarah Mohammed Mutar, and Ziad Qais Al-Abbasi

***Abstract*—This paper proposes optimizing the performance of power allocation per user in a multi-cell, multi-base stations; RIS-assisted massive MIMO system under high traffic demand conditions. The paper also investigates the weight-based interference mitigation strategy, in which the detrmental effects of each base station are suppressed using a weighting mechanism, to maximize the achievable spectral efficiency per each cell's base station, and hence improve the users' experience and enhance the provided coverage within each cell so the whole system performance is optimize. Also the study includes optimizing the phase shift of each IRS elements iteratively reduces the mutule coupling effect among them. The techniques developed could improve the spectral efficiency and overall performance of RIS-Massive MIMO assisted wireless communication systems for 6G applications.**

***Keywords*—RIS-Massive MIMO; Power Allocation; Interference Mitigation; 6G systems**

I. Introduction

THE generations of wireless communication systems are continuously developing in terms of challenges such as, the size of traffic demand, number of users to be served, quality of service (QoS) levels, and the levels of consumed power,.. etc. [1] On the other hand, one of the key solutions to cope with this evolution is to integrate two or more technologies to cooperate altogether to boost the performance of the merged individuals or create a new supreme one [1], [2], [3]. This paper is an effort to consider integrating RIS technology into a multicell massive MIMO system. Multicell massive MIMO has shown huge capabilities in terms of improving the capacity, spatial gain and achievable rates [4]. This makes it a promising candidate for 6G systems [5].

Due to its potential in boosting energy and spectral efficiencies, reconfigurable intelligent surfaces (RIS) are being regarded as one of the enabling technologies to establish 6G communication system [6]. RIS is a plane that consists of multi quasi-passive reflective elements arranged in an array that could be collectively or individually tuned to direct the transmission towards a certain direction and hence, establish a smart propagation environment and contribute to improving the overall system performance [7], [8]. The phase shifts of the RIS elements could also be controlled to mitigate the effect of the interference and allow for steering of the transmission beam [9]. Motivated by the promising potential of the RIS technology along with the solutions that massive MIMO could offer for the 6G system, this paper considered the combination of both of these technologies. In particular, this paper will also propose an interference nulling strategy that is based on optimizing the phase-shift of the RIS elements. This optimization is based on the idea of selecting the best reflections direction so as to direct the reflected transmission in the best interest of the receiving users.

A. Related Literature Works

The current and future generations of communications systems are challenged by the huge traffic demand and the large numbers of connected devices. These challenges mandate the need for developing new techniques that are able to enhance the reliability, quality and quantity of the provided services. Several solutions had been proposed in by previous studies to meet the current and the expected challenges and demands. Most of them, tend to guarantee high energy and spectral efficiencies. In particular, a considerable number of recent literature works had documented some of the challenges through the adaptation of RIS technology and these works emphasized how RIS could contribute to tackling the challenges that might face future generation wireless networks. This section presents a view of few of the literature works that highlights part of the motivation to study RIS and massive MIMO in this paper. For instance, a study conducted in [10] which focused on exploring the sum rate gains achieved through power allocation strategies in multicell massive multiple-input multiple-output (MIMO) systems in relation to time-division duplex (TDD) transmission. The findings demonstrated that the proposed scheduling mechanism yielded nearly identical performance to joint power allocation following just one scheduling round, while significantly reducing complexity. Also, [11] investigated the possibility of maximizing the energy efficiency (EE) through use of power allocation algorithm that combining power allocation (PAA) with the joint time (JT). The outcomes demonstrated that combining the JT theory with the PAA was an effective way to improve the EE. [12] optimized the reflecting elements behavior of IRS-NOMA system for 6G beside proposing modified algorithm for multiple IRS surfaces to improve the EE-SE behavior. It should be noted that the author didn't use MIMO technology. The results proved the efficient for the followed algorithm to optimize 6G IRS-NOMA system behavior. [13] presented a numerical investigation regarding the MIMO system for cell free massive technique which found that the power cost can be decreased when energy exchange technique enabled. The authors proposed a linear programing algorithm to get higher optimization for the consumed power which proved its effectiveness in enhancing the EE. In [14], the authors proposed an approach for designing zero-force (ZF) beamforming at the base station (BS) and reflection coefficients at the intelligent reflecting surface (IRS). The goal was to

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effectively remove inter-user interference. The study found that the IRS-assisted massive MIMO system, which used the same channel estimation overhead, had higher user signal-to-interference-plus-noise ratios (SINRs) than the system without IRS. However, the proposed method for this work will be limited by narrow beam-ZF limitations, that represents what we can aim at overcoming in the current study. Author in [15] offered a joint optimization approach to optimize the achievable rate of the users by optimizing location of Artificial-IRS (AIRS). The goal of this study was to determine optimal AIRS location, with the least computer complexity requirements. In order to do this, the researchers developed a fast optimal location search scheme based on the path loss model. In add ition, by using this method, the user achievable rate was increased because of the optimal AIRS position. The applications for the genetic based approaches in several generations of IRS mm Wave have been studied by [16]. The authors explored the possibility of improving the performance of IRS-mmWave through a search approach using genetic algorithm (GA) in order to determine an almost optimal set of phase shifters at the IRS. In addition, an alternating optimization approach was used to develop both the active hybrid beamforming and the passive intelligent reflecting surface together. The numerical results of their study confirmed that the IRS-assisted system outperformed the non-IRS-based system in terms of spectrum efficiency. Furthermore, it outperformed existing methods in IRAS systems. [17] also provided the performance of two transmission strategies for a multi-user huge MIMO relaying system. The paper proposed an efficient method for estimate of the channel gain at the receiver side, which aims to find only effective gains instead of entire channels. In order to further optimize power, a power control algorithm based on the max-min criterion was developed. Thereby we observed that the proposed method eliminated destination\'s requirement for estimating all sub - channels. But it was only required to compute the estimated values of the channel gains. As a result, the channel estimate overhead was insensitive to the number of antennas at both relay and destination. In reference [18], the authors of r created a system named integrated sensing and communication (ISAC) employing a distributed semi-passive intelligent reflecting surface (IRS). This permitted the simultaneous location and data transmission within the same frequency and time resources. Simulation results were used in the study to demonstrate the efficiency of proposed location sensing method, which achieved an impressive precision, well beyond millimeter-level positioning accuracy. This demonstrated the effectiveness of ISAC in achieving accurate location sensing. The above articles and others highlight the importance of IRS in assisting other technologies, such as massive MIMO, to meet the needs of 6G networks. This is one of the reasons for implementing IRS in the research conducted in this study. The contribution of this paper is combined of several aspects related to the IRS-massive MIMO system. The overall aim is to tackle the expected challenges of 6G system. These contributions could be summarized as follows:

- Proposing a BS-weight based interference mitigation technique where each BS is assigned a weight to settle its detrimental effect upon its counterparts within each cell and also among different neighboring cells.
- Optimizing the allocability of the users' transmission power so as to improve the overall users' experience and enhance the provided coverage within each cell.
- Optimizing the phase shift of each IRS element to perform constructive direction of the transmission reflection toward the active users. This optimization is applied while taking into account reducing the interference level, so it could be also considered as another interference mitigation technique.

II. The System Model Under Consideration

The purpose of this essay is to suggest a downlink for a multi-cell, multi-user mMIMO transmission system. It is supposed that the users are exploring the coverage area under consideration in a random manner and seeking services. Additionally, it is expected that there is a dense traffic demand in order to simulate 6G scenarios. For the purpose of providing service to a total of K active users, the proposed system is comprised of a total of L base stations, each of which is presumed to have massive MIMO technology installed. Additionally, it is believed that each user possesses one antenna. In order to improve the conditions of the cell-edge users, the propagation environment is thought to include the RIS surface. In this scenario, it is believed that the RIS is furnished with a total number of reflecting elements equal to N. At the receiving end, the signal that was received by the i-th user might be expressed as

$$y_{l,i} = \sum_{l=1}^{L} \left(H_{l,i}^{(bs-user)} + g_{l,i}^{(bs-ris)} \Theta_{l,i} g_{l,i}^{(ris-user)} \right)^{H} \mathrm{x}_l + \quad n \ , \qquad (1)$$

where $h_{l,i}^{bs-user}$, represent the wireless channel that links between the l-th BS and the i-th user, the term $g_{l,i}^{(bs-ris)}$ stands for the channel gain that connects between the l-th BS and the RIS plane surface. Finally, the term and $g_{l,i}^{(ris-user)}$ stands for the channel gain that connects between the RIS plane and the i-th user, respectively.

A. Description of the Proposed IRS structure

The magnitude and phase of each reflective elements in the RIS surface is referred to by the variable $\emptyset$ which is expressed by $\emptyset = \left[\kappa_n e^{j\emptyset_n} \right]^T$. Where θ refers to the reflection phase shift and its values range between zero to 2π, and n=1 to N which is an index that refers to the reflection element order. $\mathrm{X}_l = \sum_{i=1}^{U} \sqrt{p_{l,i}} \mathrm{v}_{l,i}\, s_{l,i}$ represent a combined signal that is being sent by the l-th BS. Where $p_{l,i}$ represents the power allotted to the i-th user who is connected to the l-th BS, and the term $\mathrm{v}_{c,u}$ refers to the precoding vector that is uses by the BS to spatially control the direction of the transmitted signal towards the intended user. Finally, the variable $s_{l,i}$ represents the transmitted information symbol that is intended for the i-th user. It is presumed that the wireless channel under consideration combines both the large scale and the small-scale fading effects. The effects of the distance between the user and the BS, the path loss exponent, the shadowing effects, and the noise figure factor, along with the noise figure factor, are all included in the large-scale phase of the analysis. The modelling of it is done in compliance with the path-loss requirements of 3GPP-LTE [25], [26], and it might be stated as

$$\Gamma_{l,i}^{large-scale} = -143 - 10\alpha \log_{10}\left({}^{d_{l,i}}/_{1\ km} \right) + \zeta_{l,i} + \varpi_{l,i} \ , \qquad (dB) \quad (2)$$

One can get a peek of the system model that is being considered by looking at Fig. 1 below. It is important to note that the positions of the RIS plane are not fixed, and they are picked at random in order to take into consideration a number of different scenario instances. This is because it is more applicable to the practical scenario that was explored in [27], [28].

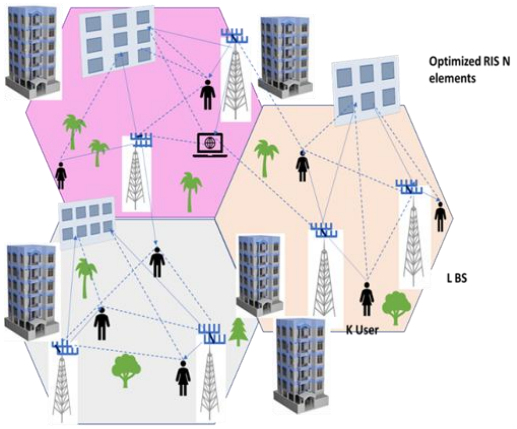


Fig. 1. System model under consideration.

B. The proposed interference-mitigation optimization problem formulation

The major goal of the problem that has been set is to discover the ideal weights of contribution for each BS in order to achieve the greatest possible reduction in interference. As an additional objective, the challenge tries to maximize the amount of power that is distributed to each individual user while simultaneously taking into account the overall power limitation. According to the equation, the objective function that is represented by the feasible SE of each cell, which is indicated by,,,,, is provided by the equation:

$$\psi_j^m = \sum_{k=1}^{K} \log_2\left(1 + SINR_j^k\right) \qquad Bit/sec/Hz \quad (3)$$

Where $SINR_j^k$ stands for the received signal-to-interference ratio by the *k*-th user communicating with the *j*-th BS.

$$SINR_j^k = \frac{P_k^j \left|h_k^j\right|^2}{\sum_{\substack{m=1 \\ m\neq j}}^{L} P^m |h_k^m|^2 + \sigma_k^2} \quad (4)$$

Where P_k^j defines the power allocated to the *k*-th user at the *j*-th BS, and $\left|h_k^j\right|^2$ refers to the channel power between the *k*-th users and its *j*-th serving BS. The term $\sum_{\substack{m=1 \\ m\neq j}}^{L} P^m |h_k^m|^2$ represents the interference effect of the other BSs on this user. Finally, the additive white Gaussian noise (AWGN) affecting the *k*-user is modelled as σ_k^2. To represent the formulated problem mathematically, the equations (2) to (4) are written as follows

$$\max \quad \psi_j^m \quad (5)$$

$$Subject\ to \sum_{k=1}^{K} P_k^j \leq P_{total}^m \quad (6)$$

$$P_k^j \geq 0, \forall k, \forall m \quad (7)$$

Equation (5) states that the goal function is a representation of the SE that was achieved by the j-th user in the m-th cell. This objective function is a representation of the SE. In equation (6), the term that represents the total power restriction guarantees that the power that is distributed among the users who are communicating does not exceed the maximum limit. This is done to ensure that the power does not exceed the maximum limit. In contrast, equation (7) stipulates the constraint that ensures a positive amount of power is allocated to each and every *j*-th user. Because the objective function of the issue at hand is logarithmic, it has been proved that the problem in question has a concave nature. A constrained-maximizing solver software from the MATLAB toolbox is used to determine the numerical solution to the issue that has been presented. In order to investigate the core of the issue that has been described, it is possible to make use of the first and second derivatives on the objective function, which are represented by the symbol SE and are referred to as ψ-j-m in this particular case. Because of this, it is essential to evaluate the sign of the expression that produced the outcome. For the sake of clarification, the allocated power and beamforming vectors are taken into consideration as optimizing variables in the formula, $SINR_j^k$ included in equation (4). As a result, the derivative will be applied with regard to the function X-Y-Z in the way that is described below:

Given that

$$\psi_j^m = \sum_{k=1}^{K} \log_2\left(1 + SINR_j^k\right) \qquad Bit/sec/Hz \quad (8)$$

Then we will use the first derivation of the expression in (3) to check concavity. It must be noted that σ_k^2 is constants. Then

$$\frac{d\psi_j^m}{dP_m^k} = \frac{1}{\ln(2)} * \frac{1}{1+\frac{P_k^j \left|h_k^j\right|^2}{\sum_{\substack{m=1 \\ m\neq j}}^{L} P^m \left|h_k^m\right|^2 + \sigma_k^2}} * \frac{\left|h_k^j\right|^2}{\sum_{\substack{m=1 \\ m\neq j}}^{L} P^m \left|h_k^m\right|^2 + \sigma_k^2} \quad (9)$$

After that, it is possible to explore the sign of the obtained first derivative expression over several regions as follows:

- Region 1: for the values where

$$P_k^j < -\frac{\sum_{\substack{m=1 \\ m\neq j}}^{L} P^m |h_k^m|^2 + \sigma_k^2}{|h_k^m|^2}$$

At this region, the 1st derivation is going to be undefined.

- Region 2: for the values where

$$\frac{-\left(\sum_{\substack{m=1 \\ m\neq j}}^{L} P^m |h_k^m|^2 + \sigma_k^2\right)}{\left|h_k^j\right|^2} < P_k^j < \infty$$

At this region, it is clear that the obtained first derivation is always positive valued.

- Region 3: for the values where

$$P_k^j = -\frac{\left(\sum_{\substack{m=1 \\ m\neq j}}^{L} P^m |h_k^m|^2 + \sigma_k^2\right)}{\left|h_k^j\right|^2}$$

At this region, the first derivative is also undefined as in the case of region 1, as it has negative range of values. By revising possible range of values within the specified limits in the above regions, it is clear that the first derivative of ψ_j^m is positive only for the case where

$$P_k^j > -\frac{\left(\sum_{\substack{m=1 \\ m\neq j}}^{L} P^m |h_k^m|^2 + \sigma_k^2\right)}{\left|h_k^j\right|^2}$$

This is because the function has increasing behavior in this region and, hence, reflect a concave nature. To sum up, the function is concave.

C. The proposed phase-shifts optimization of IRS-elements

In addition, this study advises that the phase shifts of each IRS element be optimized in an iterative way in order to have extra control over the propagation environment. This is done to allow for greater control over the environment. An idea that is often referred to as the iterative searching gradient technique serves as the basis for the optimization approach that has been established. It helps to enhance the phase shift while simultaneously helping to the decrease of interference. In addition, it helps to improve the phase shift. One of the advantages of maximizing the phase shift is that it may bring about a reduction in the mutual coupling that occurs between the IRS components. This can be accomplished by increasing the phase shift among the IRS elements. Algorithm I below shows the procedure followed to perform the proposed scheme.

Algorithm 1
Iterative gradient searching approach to optimize the IRS phase shifts

- Initialize the parameters: the phase shifts per element, N, K, L, M, H, total iterations, tolerance (τ), step-size (ρ)
  - For each BS at the l-th cell, (for l = 1 to L)
    - Calculate the interference level at the current phase shifts

$$I_{before} = \sum_{l=1}^{L}\left|\sum_{m=1}^{M}\sum_{k=1}^{K} H_{m,k}^{l} x_n'\right|^2$$

    - Update the values of the phase shifts according to the gradient-search approach:

$$\vartheta = -2\left|\sum_{m=1}^{M}\sum_{k=1}^{K} H_{m,k}^{l} x_n'\right|^2 \left(\sum_{i=1}^{L} H_{m,k}^{l} x_n'\right)'$$

    - Updating the phase shifts of all elements

$$x_n = x_n + \vartheta\rho$$

      - Check the projection of the resulted phase shifts within the set of 0 to 2π through performing:

$$x_n = mod\left(ang\left(x_n\right), 2\pi\right) * e^{j\left(ang(x_n)\right)}$$

      - Check the convergence rate according to the variations in interference power levels, where Iinterf(prev.)-Iinterf(prev.) should be less than the tolerance (τ)
      - If there is no reduction in interference, record the current phase shifts (means there is no better phase shifts)
      - Return the obtained phase shifts
- end

IV. SIMULATIONS AND RESULTS

This section presents the findings of the simulations applied within the work of this paper. The values of the parameters exploited within the simulations shown in Table I

Those values were selected to conform to the 6G standards.

TABLE I
VALUES SELECTED TO CONFORM TO THE 6G STANDARDS

Parameter	Assigned value
No. of cells (BSs)	6
No. of users per cell	15
Total BS power	30dBm
No. of antennas at the BS	64, 128
No. of IRS elements	8, 32

The findings that follow analyze the process that the numerical *fmincon* solver in the MATLAB program takes in order to arrive at the optimum value while simultaneously fulfilling the stated limits inside the defined problem. This investigation is conducted for a specific iteration of the optimization problem code. Due to the random nature of the different variables included inside the system model that is being investigated, this is not always the case. Some of these factors might potentially have an effect on the search space in order to find the best value. The particular scenario that was analyzed and shown in Table 2 reveals that the ideal answer was only achieved after about seven iterations. On the other hand, this is not always the case. As an illustration, it may take as many as hundreds of iterations depending on a wide range of parameters. These parameters include, but are not limited to, the random changes that are introduced by the channel, the large-scale fading factors, the locations of the users in relation to the base station that is providing the service, and the interference levels.

TABLE II
TEST-OUTCOME OF THE PROPOSED OPTIMIZATION PROBLEM BY ADOPTING THE FMINCON NUMERICAL SOLVER

Iter	F-count	f(x)	Feasibility	Optimality	First-order Norm of step
0	22	-2.169040e+03	0.000e+00	4.117e+02	-
1	44	-1.353388e+04	0.000e+00	2.113e+05	1.431e+00
2	66	-4.487717e+04	0.000e+00	2.310e+07	5.473e-02
3	88	-8.996596e+04	0.000e+00	1.872e+05	2.396e-02
4	110	-9.309410e+04	0.000e+00	6.913e+08	1.542e+00
5	132	-1.278177e+05	0.000e+00	1.174e+04	3.681e-02
6	154	-1.278591e+05	0.000e+00	1.914e+06	6.666e-03
7	176	-1.887494e+05	0.000e+00	1.262e+04	1.446e-01

A bar chart that depicts the optimum power allocation for each user is shown in Fig. 2 below. This is done for the purpose of presenting a case study run of the proposed technique. Over the course of this specific instance, this is the total quantity of power that has been dispersed among the fifteen customers who are considered to have a need for service. In order to ensure that the power levels that have been assigned are in compliance with the overall power limitation and that they attain a value of about 9.8575W for the run scenario that is being explored, it is required to check that these power levels have been assigned. Because it still has unused power that is lower than the total transmission power that is allotted, which is 10W, this is a reflection of the fact that the suggested optimization problem leads to energy-efficient power allocation. This is because it still has unused power. On the other hand, in order to address the issue of interference that causes the feasible SE to be affected.

There is a proposal for an interference mitigation strategy that is based on optimizing the weights of each base station in order to control the contribution that each BS makes to the interference that is created. The optimized weights that have been assigned to each BS are displayed in Fig. 3. This is being done in order to keep the interference level as low as possible in order to achieve the highest possible SE values.

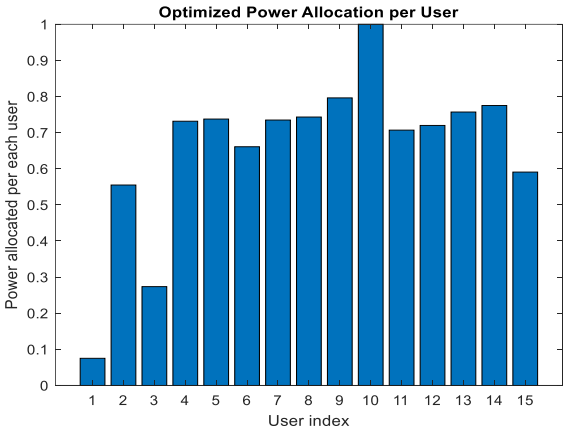


Fig. 2. Optimized power allocability among several users in an optimal manner that suits each user's channel conditions.

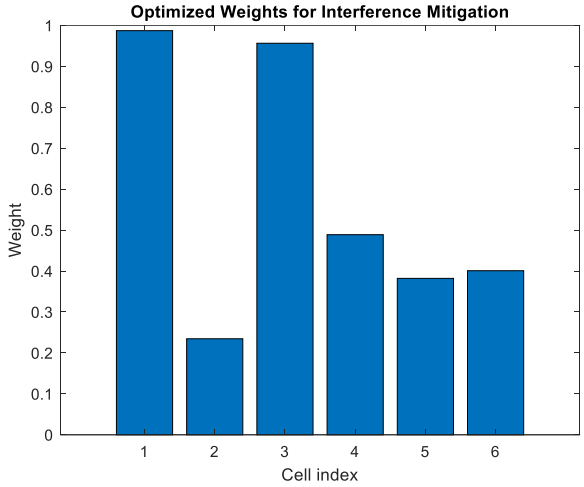


Fig. 3. Interference mitigation strategy with optimized weight per each BS within each cell.

The impact of performing the proposed adaptive interference mitigation strategy is depicted in Fig.4 below. As shown in this figure, the proposed adaptive interference mitigation strategy that has been devised is demonstrated. In spite of the fact that the interference level is growing, which is because of the increase in the number of cells and BSs, there is a discernible decrease in the interference level once the mitigation strategy has been implemented as it works iteratively on reducing the level of the interference. By way of illustration, when there are six cells, there is a reduction of around eleven decibels in the interference level. In addition to improving the overall performance of the system, this is essential in order to increase the rate that can be achieved by each individual user within those cells. In addition, it is essential to combat interference, particularly in dense environments that are characterized by congested transmission and reception as well as a wide range of services, which is the situation with 6G networks.

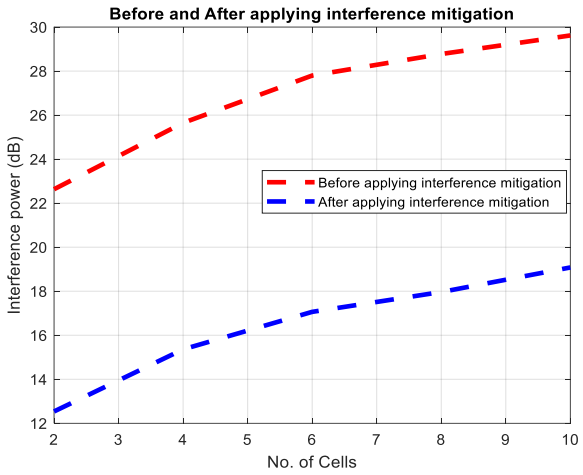


Fig.4. The proposed adaptive interference mitigation strategy with optimized weight per each BS.

Regarding the IRS surface, Fig.5 illustrates the best phase shifts for each individual element. In order to gain the most benefits and to assist in the creation of a propagation environment that leads to the highest data rates, spectrum, and energy, the objective of optimizing the phase shifts is to ensure that the reflection from IRS elements is directed in the most advantageous direction feasible direction. efficiencies outcome that is suitable for 6G services.

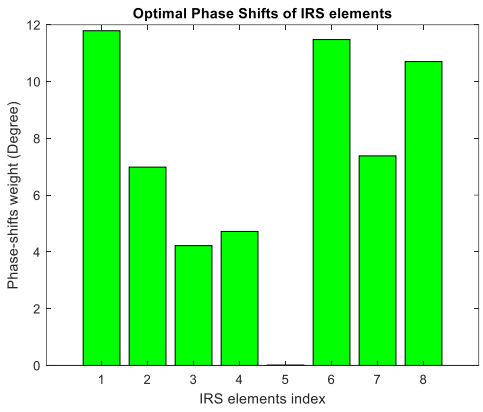


Fig. 5. The proposed adaptive interference mitigation strategy with optimized weight per each BS

CONCLUSION

This research was undertaken to investigate how to optimize the allocated power and beamforming of a downlink of an IRS-assisted massive MIMO system. The analysis was carried out in order to discover how to optimize these aspects. It is feasible to maximize the overall performance of the system by formulating an optimization problem with the objective of maximizing the potential data rate per each cell's BS. This kind of problem is used to optimize the system. There has been a suggestion that a new concept should be established in order to control the role that each BS performs in contributing to the overall performance of the network. To be more explicit, the weight of an improved BS is integrated into the formulation of the optimization problem in order to improve the overall performance and reduce the negative effects among the multiple BSs that are positioned in close proximity to one another. This is being done in order to maximize the overall performance.

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